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Cerrado Rupestre is not Campo Rupestre: The unknown and threatened savannah on rocky outcrops

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The Cerrado Domain (Cerrado *sensu lato*) covers about two million km^2 of Brazilian territory and consists of forest, savannah and grassland biomes, having dozens of phytophysiognomies that usually occur in mosaic, varying within this spectrum of different biomes (Ribeiro and Walter 2008; Batalha 2011). Amid so much diversity of species, life forms and geological aspects, some of its phytophysiognomies are not well known, being lost in the wide spectrum of vegetation present in the Cerrado.

In general, the Cerrado is physiognomically characterised by typical savannah vegetation, with a lower occurrence of forest and grassland formations (Ribeiro and Walter 2008; Overbeck et al. 2022). Amongst the savannah phytophysiognomies, the Cerrado *sensu stricto* stands out, the savannah with the greatest biodiversity in the world (Fernandes et al. 2016), which is subdivided into Cerrado Denso, Cerrado Típico, Cerrado Ralo and Cerrado Rupestre, based on the densities of the shrub-tree and subshrub-herbaceous components and substrate properties (Ribeiro and Walter 2008). The first three savannah subdivisions show higher floristic similarity and occur in deep soils with vegetation cover ranging from 70% to 5%, respectively (Ribeiro and Walter 2008).

The Cerrado Rupestre is the rarest and most unknown Cerrado *sensu stricto* subdivision, occurring to a lesser extent in rocky outcrops, mainly in reliefs above 800 m of altitude along the Serra do Espinhaço range (Minas Gerais and Bahia States), in the Central Plateau in Goiás and in the Serra dos Carajás, in the State of Pará. The Cer-

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rado's mountaintops occupy an estimated area of only 7% of the Cerrado Domain (Reatto et al. 1998), where the Cerrado Rupestre often occurs together with the Campo Rupestre, a grassland phytophysiognomy with which it is often confused. Both share the same climate conditions, according to the classification of Köppen, varying from subtropical altitude (Cwb), tropical altitude (Cwa) and humid tropical (Aw), the first two with dry winters and mild summers and the last one hot and humid (Alvares et al. 2013). The soils are litholic and originated from the decomposition of sandstones, iron ores and quartzites. They are poor in nutrients and acids, with low levels of organic matter (Ribeiro and Walter 2008). The vegetation of these rupestrian environments is characterized by the occurrence of species typical of savannah and grassland formations of the Cerrado Domain, but also by restricted species due to the different microhabitats such as cracks, fissures and exposed rocks, providing a high degree of endemism, with several species threatened with extinction (Fernandes et al. 2020).

Although Cerrado Rupestre and Campo Rupestre can occur in mosaics in rocky outcrops (Fig. 1), both on quartzitic soils and on canga (ferruginous soils) (Fig. 2A–D), they differ in the density of shrub-tree and subshrub-herbaceous components (Ribeiro and Walter 2008) and floristically (Fernandes et al. 2020). The Cerrado Rupestre is a savannah phytophysiognomy and presents a tree cover varying from 5% to 20%, an average height of 2 m to 4 m and a highlighted shrub-tree stratum (Fig. 2A, C), while the Campo Rupestre is a grassland phytophysiognomy, with a predominance of an herbaceous-shrub stratum with less than 5% tree cover (Fig. 2B, D). As they are in an ecotone, they share some species, but have floristic differences and many different indicator species. Amongst the indicator species of the Cerrado Rupestre, we can highlight woody species, such as *Mimosa setosissima* Taub., *Tibouchina papyrus* (Pohl) Toledo, *Wunderlichia mirabilis* Riedel ex Baker, amongst others (Ratter et al. 2000; Ribeiro and Walter 2008; Pinto et al. 2009), while for the Campo Rupestre, we can highlight *Coccoloba cereifera* Schwacke, *Comanthera elegantula* (Ruhland) L.R.Parra & Giul., *Paepalanthus bromelioides* Silveira, amongst others (Brazilian Flora 2022).

These floristic and tree cover differences between Cerrado Rupestre and Campo Rupestre can be explained by different microclimatic variables and factors, such as soil depth and amount of exposed rock (Gianotti et al. 2013). Although they can occur in nearby areas, the Campo Rupestre usually occurs at the top of the hill at higher altitudes (Fig. 1) and is significantly distinguished from the Cerrado Rupestre mainly concerning the higher wind speed, lower relative humidity, lower water vapor pressure, and lower thermal amplitude, factors that limit a higher tree cover (Gianotti et al. 2013). In addition, the Campo Rupestre generally presents a more stony and shallow soil. Consequently, the soil texture of the Campo Rupestre is sandier and retains less water than the Cerrado Rupestre, which receives water from the leaching of soluble materials from the rains, accumulating higher contents of organic matter and clay, two elements that have a noticeable influence on the water holding capacity of the soil (Gianotti et al. 2013).

Finally, the plant species in these environments can also vary in their fire resistance (Neves and Conceição 2010). Fire is known to be one of the most important factors in the dynamics of Cerrado plants and these two environments present several species adapted to fire, presenting characteristics, such as thick rhytidome, xylopodia, tubers,

Figure 1. View of a quartzite rocky outcrop showing Cerrado Rupestre (at the bottom of the hill) and Campo Rupestre (top of the hill) vegetation occurring in a mosaic on Serra de São José, Prados, Minas Gerais, Brazil. Photo credit: Cássio Cardoso Pereira.

bulbs, corms and underground rhizomes (Coutinho 1982). However, the Campo Rupestre presents a higher number of species sensitive to the action of fire that survive in rocky areas, where the restriction of fuel prevents the arrival of fire in individuals isolated by the rock. As a result, the invasion of exotic grasses increases fire on mountain tops, putting these species at risk (Neves and Conceição 2010).

However, despite being side by side in the same environment, occupying less than 2% of the national territory, harbouring about 1/3 of the plant biodiversity, being a cradle of Brazilian waters and suffering the same type of threats, mainly due to economic activities, such as livestock and mining (Reatto et al. 1998; Silveira et al. 2016), the Cerrado Rupestre remains even more unknown and neglected than the Campo Rupestre. In a survey in the SCOPUS and Web of Science databases, searched by the names "Campo Rupestre" and "Cerrado Rupestre" in the title, abstract and keywords, 808 publications were found about Campo Rupestre and only 35 about Cerrado Rupestre between 1989 and 2022. Could it be that part of the work with rocky outcrops considered the vegetation to be from Campo Rupestre without taking into account its differences with the Cerrado Rupestre? Or could part of the work carried out in the Cerrado Rupestre environment have been indistinguishable from the Cerrado *sensu stricto*? In any case and regardless of the physiognomic nomenclature used, publications about Cerrado Rupestre are scarce and mostly restricted to floristic works, lacking information on local fauna, ecological interactions, ecosystem services, restoration and conservation (Pereira et al. 2022).

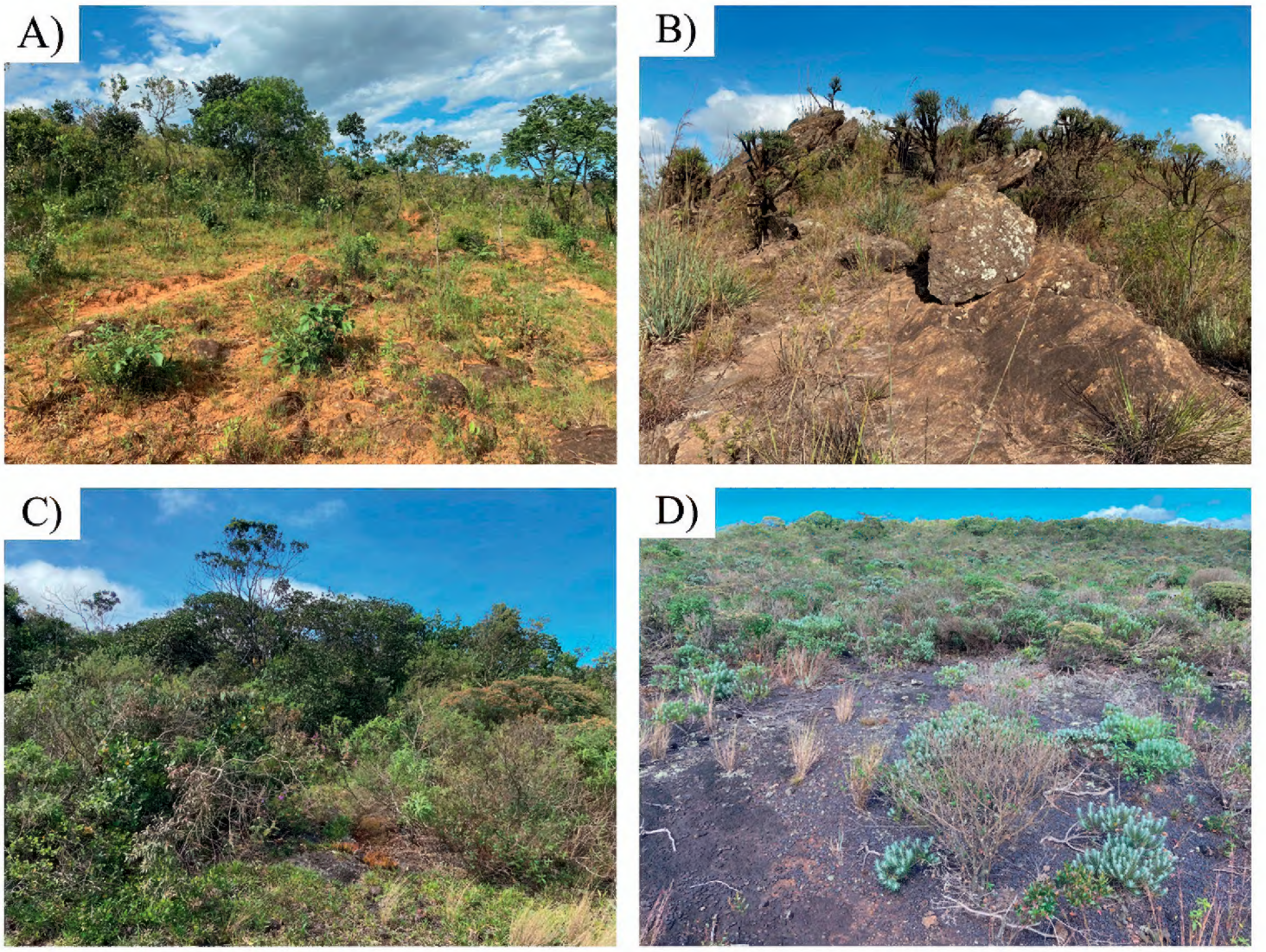

Figure 2. Phytophysiognomic differences between Cerrado Rupestre and Campo Rupestre. Although they can occur in mosaics on rocky outcrops, both on quartzitic soils (**A** and **B**) and on canga (ferruginous soils, **C** and **D**), the Cerrado Rupestre is a savannah phytophysiognomy and presents a tree cover between 5 and 20%, while the Campo Rupestre is a grassland phytophysiognomy, with a predominance of a herbaceous-shrubby stratum with less than 5% tree cover **A** Cerrado Rupestre over quartzitic soil in the Municipality of Congonhas, Minas Gerais, Brazil **B** Campo Rupestre over quartzitic soil in Serra do Ouro Branco State Park, Ouro Branco, Minas Gerais, Brazil. Cerrado Rupestre (**C**) and Campo Rupestre (**D**) on canga soil in Serra do Rola Moça State Park, Nova Lima, Minas Gerais, Brazil. Photo credits: Cássio Cardoso Pereira.

Restoring rupestrian environments is fundamental, but represents a major challenge, as we still do not know how to restore these ecosystems, which are often considered degraded forests by decision-makers (Veldman et al. 2019). As a result, many restoration actions in these areas mistakenly use tree planting (Veldman et al. 2019). Furthermore, the recovery of these rupestrian environments after a disturbance is extremely slow (Le Stradic et al. 2014). In Cerrado Rupestre, after use for pasture or forestry, there is a successful recovery of the tree component, but the native subshrub-herbaceous layer does not recover (Overbeck et al. 2022). This characteristic is very alarming because there are practically no seeds of native species on the seed market. Therefore, it is still very challenging to restore these ecosystems (Veldman et al. 2019).

Studies show that these environments may disappear in the coming decades due to ever-growing agribusiness and mining practices that replace native vegetation with extensive areas of monoculture, livestock and ore extraction (Fernandes et al. 2016;

Fernandes et al. 2018). Furthermore, we cannot forget that these environments are also being impacted by global warming (for example, increasing temperatures, fire frequency and changes in the amount of rainfall), which have been affecting the reproductive success of plants (Vilela et al. 2017) and indirectly affecting the dynamics of communities (Memmott et al. 2007). Unfortunately, this scenario has been intensifying frighteningly in recent years. Coupled with the need for more studies to better understand these environments and restore them, there is an urgent demand to expand the current shameful 8.21% of legally protected areas in the Brazilian Cerrado (Pereira and Fernandes 2022), so that the Cerrado Rupestre can be properly studied before it will be destroyed.

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